Upadhyay, B.M. and D.L. Young. “Stochastic Breakeven Yields for Investment Risk Analysis.” *Journal of Financial Risk Management,* ICFAI University Press, 4(2)(2007):26-36.

STOCHASTIC BREAK EVEN YIELDS FOR INVESTMENT RISK ANALYSIS

Bharat M. Upadhyay and Douglas L. Young

Investment Risk and Stochastic Breakeven Yields

Authors are Senior Risk Analyst, Agriculture Financial Services Corporation, Lacombe, Alberta, Canada and Professor, School of Economic Sciences, Washington State University, Pullman, Washington, USA. The U.S. Dept. Ag.-STEEP Project provided financial support for this research.

STOCHASTIC BREAK EVEN YIELDS FOR INVESTMENT RISK ANALYSIS

Keywords: breakeven yield, investment risk, Monte Carlo simulation, no-till, rent-purchase, risk, safety first, technology adoption, transition strategy

Abstract.

A new concept, stochastic breakeven yields, is used to illustrate risk levels of short and long run transitions to new technology. The breakeven yield implies the same probability of dynamic business failure for the old and new technologies. The framework has intuitive appeal because while price is beyond the farmer's control, a farmer often has some perception of likely yield performance. An application to the transition to no-till farming showed that breakeven yield premiums to make no-till farming equally risky as conventional tillage farming varied with farm size, proportion of rented land, and transition strategies. Yield premium minimizing choices were consistent across planning horizons. Immediate adoption of no-till was preferred for large farms when the transition involved buying a no-till drill. For smaller farms, the preferred transition strategy was to rent a drill and gradually expand no-till area.

STOCHASTIC BREAK EVEN YIELDS FOR INVESTMENT RISK ANALYSIS

Farmers and other businessmen are interested in both the short run stability and the long run survival of their business. A key to achieving these objectives is making appropriate decisions on day-to-day tactical adjustments and on major investments (Kingwell, Pannell and Robinson). Major investments require appropriate multi-year risk management decisions.

Recent concern about on-farm and off-farm effects of soil erosion and rising tillage costs have raised questions on the long term sustainability of conventional tillage Papendick 1996). Minimum tillage and no-tillage have emerged as the preferred alternatives for environmental reasons, but may be economically risky (Papendick 1998; Schillinger; Janosky, Young and Schillinger). The transition to no-till requires major cash outflows for a no-till drill. Also the farmer may face an extended learning curve for mastering the new technology during the transition. The transition is risky due to the stochastic nature of yields and prices. Risk exposure will vary with the size of farm and equity position. Risk management involves choosing among several speeds of expanding no-till area and choices of no-till drill acquisition options. There is evidence that mastering the risky no-till transition is worthwhile because some established no-till farms have been profitable (Camara, Young, and Hinman).

Most risk analyses in agriculture have used the expected utility maximizing framework (Buschena and Zilberman) or a safety-first framework (Kataoka; Telser; Roy). However, some analysts have expressed dissatisfaction about the applicability of expected utility for extension use (Just; Castle; Selley and Wilson; Anderson and Mapp).

Pannell et al. observed that major long run decisions are largely ignored in expected utility applications compared to annual decisions. Just indicated the need for long as well as short run risk analysis. When farmers are risk averse, safety-first approaches have been found to provide practical approaches to some business risk management problems (Upadhyay and Young). Pannell et al. have noted that simple break-even yields and prices can incorporate some risk considerations into the decision process. Ortmann et al. state that farmers' desire for risk management information is largely concerned with defining expected outcomes. However, Selley and Wilson have noted that producers' demand for specific strategies and for odds of success has made probabilities of failure (or success) the most popular component of teaching risk management.

This study proposes a stochastic break-even framework for investment risk analysis. The analysis provides understandable expected yield premiums attached to each investment alternative which leave the farmer with equivalent safety-first risk exposure between the old technology and new technology. The framework has intuitive appeal because while price is beyond the farmer's control, a farmer often has some perception of likely yield performance given resource limitations and knowledge of the new technology.

The specific objective of this study is to derive yield premiums for several no-till investment transition strategies which break even with respect to safety-first risk compared to conventional tillage for both short and long run planning horizons.

General Model

This study, introducing the breakeven stochastic yield concept for risky decisions, employs results of the farm risk simulation model described by Upadhyay and Young which computes simple probabilities of business failure. Selley and Wilson have reported that farmers prefer simple probabilities as understandable risk measures for risky alternatives. Roy's safety-first rule complies with this preference for probability information. Mathematically, Roy's criterion is:

$$\text{(1)} \qquad \text{Min } \Pr(NCF_j \leq NCF^*), \text{ j = 1,2,…,n decision options}$$

Where Pr is the probability, NCF_j is the stochastic annual net cash flow that differs year-to-year for strategy *j* and *NCF** is the critical level of *NCF*. In this study net cash flow (NCF_j) varies with the farm type, tillage system, and planning year, is estimated (with "j" subscripts suppressed and tildas denoting stochastic variables) as:

$$\text{(2)} \qquad NC\tilde{F} = \tilde{P} * \tilde{Y} + \tilde{G} - \tilde{S} - FC - VC - \tilde{T}_X$$

Annual $NC\tilde{F}$ was simulated with 500 stochastic runs over the transition period with the whole farm simulation model discussed below (Richardson; Upadhyay and Young). $\tilde{P}$ and $\tilde{Y}$ are the stochastic prices and yields. $\tilde{G}$ is the stochastic government payment under the 2002 USA Farm Bill. $\tilde{S}$ is the stochastic annual crop share paid for any rental land. $\tilde{T}_X$ is the stochastic personal tax on taxable net revenue assessed at the end of a year. FC is the annual cash fixed costs that include property taxes, machinery, machinery payments, taxes and insurance, and other cash overhead costs. For the no-till drill, annual machinery costs vary depending on form of drill acquisition. For a purchased drill, year 1 includes the down payment. Deterministic *VC* excludes operator labor which is a noncash cost. Following Upadhyay and Young (2006), the critical level of *NCF* is estimated in this study as:

(3) $$NCF^* = C$$

Where, C is the expected annual household consumption expenditure. Consumption expenditure is conditional on before-tax *NCF,* which varies across type of farm. Annual consumption increases over time due to inflation.

Let crop yield distributions for no-till and conventional till respectively be $\tilde{Y}^N$ and Y^C. Price distributions for the same crop are identical for no-till and conventional till. We will seek to find the multiplicative yield expansion, $1+P-\theta$, applied to the no-till yield distribution ($\tilde{Y}^N$) that causes the probability of falling below target income to be equal for no-till and conventional till. In this study, θ is a 10% yield penalty for no-till relative to conventional tillage in year one which linearly disappears by year 6. This implies the expected no-till yields were 90% of the conventional tillage in the first year progressing towards 100% in the sixth year. θ represents the "learning curve" for mastering the no-till technology. In essence, P is the fixed percent no-till yield premium necessary to accelerate this learning curve to achieve stochastic economic equality.

Figure 1 displays a linear learning curve and fixed yield premium. Along the vertical axis is the expected yield (μ) and along the horizontal axis are the transition years (t). The expected yield of conventional tillage (μ^C) is assumed constant over the transition period. The no-till yield penalty (θ) decreases linearly over time. The figure shows a hypothetical fixed breakeven no-till yield premium (P) of 5 percent. Coupled with the initial no-till yield penalty of 10 percent, no-till yields equal conventional till yields by year 3 and surpass them thereafter. In essence, P reflects the farmer's perceived ability to shift his/her no-till learning curve upward.

Mathematically, an average year problem in this study can be defined as:

(4) Find P

$$\text{Such that } \mu^N = \mu^C(1 + P - \theta), \ \forall\ \theta \geq 0,\ P \geq 0$$

$$\text{and } \Pr(NC\tilde{F}^N \leq NCF^*) = \Pr(NC\tilde{F}^C \leq NCF^*)$$

Where μ^N and μ^C are mean no-till and conventional till yields. $NC\tilde{F}^N$ and $NC\tilde{F}^C$ are the stochastic net cash flows for no-till and conventional till farm, respectively.

Empirical Methods

Farm and Transition Scenarios

The study utilizes data from an 18-22 inch annual precipitation region of eastern Washington state, USA. Farm size and equity vary considerably in this region (Hall et al.). For this study, four size and equity combinations within the typical range are examined: A large farm (3,000 ac) with a high proportion (0.80) rented land is referred to as LFHPR, a large farm (3,000 ac) with a low proportion (0.20) rented land is referred to as LFLPR, a small farm (800 ac) with a high proportion (0.80) rented is referred to as SFHPR, and a small farm (800 ac) with a low proportion (0.20) rented is referred to as SFLPR.

A local survey of no-till farmers (Juergens et al.) revealed that farms differed in their speed of adoption of no-till. Therefore, two no-till adoption rates were simulated in this study: Immediate adoption (IA) over the entire farm during the first year of the transition and gradual adoption (GA) with 5% of the farm under no-till in the first year that linearly increases up to 30% by the final sixth year of the transition period.

The mode of no-till drill acquisition through custom hire, rent, and/or purchase over the six-year transition period will significantly influence a farm's annual net cash flows. The year a drill is purchased annual cash outflow will increase due to down payment obligations. The five drill acquisition sequences simulated in this study are rent in all six years (R-6), rent for three years and then purchase (R-3), purchase in year one (P-6), custom hire for three years and then purchase (C-3), and custom hire all six years (C-6).

Stochastic Simulation Approach

For a multivariate distribution of prices and yields, stochastic simulation has been proposed as a useful method for risk simulation (Lien). Two alternative approaches for stochastic simulation reviewed by Lien (2003) differ in how stochastic dependencies between the variables are incorporated in the model. The hierarchy of variable approach requires selection of macro-level variables to which all costs are expected to be correlated. This approach is preferable when historical data are not relevant in the policy model (Hardaker, Huirne and Anderson). The other alternative, a multivariate empirical distribution approach proposed by Richardson, Close and Gray, was used for this study appropriately correlating historical yields and prices (Upadhyay and Young).

Stochastic cash inflows included gross receipts generated from stochastic prices and yields for winter wheat, spring barley, and spring peas. Gross receipts were net of crop shares paid for the rented portion of the land and included net annual government payments. Cash outflows included deterministic fixed and variable crop production expenses, drill costs, annual taxes, and family living withdrawals. After-tax annual net cash flows were simulated for each of the four types of farms with 10 alternative no-till transition strategies (5 drill acquisition modes x 2 speed of adoption) and one conventional tillage strategy. Each farm scenario by strategy was simulated stochastically 500 times for each year in the six-year transition using a Monte Carlo simulation program (Richardson; Upadhyay and Young).

Breakeven Yield Premiums and Decision Criteria

Risk associated with alternate machinery acquisition and use decisions was measured using the stochastic breakeven framework described earlier. The breakeven yield premiums were generated for each no-till and conventional tillage strategy for all four types of farms. The yield premiums were computed by shifting the no-till yield distribution until the probability of net cash flow falling below a target level was equal for no-till and conventional tillage.

Transition business failure was based on two criteria: a short run criterion defined business failure as a negative cash balance in two consecutive years of the six-year transition and a long run criterion defined business failure as a negative cash balance at the end of no-till transition.

Data

Data for this study are adopted from Upadhyay and Young and are briefly summarized here. Yield data from a wheat-barley-pea tillage experiment in eastern Washington were used to generate the multivariate yield distributions for both conventional and conservation tillage (Boerboom et al.; Hall; Young, Kwon and Young). Every crop in a rotation was grown every year in the experiment. The expected yield for conventional tillage during the transition was set at the nine-year average level from the experiment. FAPRI (Iowa State University) projected farm level prices for the transition years were localized to generate expected wheat and barley prices (Mitchell and Black). Pea prices, due to absence of national and local forecasts, were linearly projected from historical state level average prices. Multivariate price variability from the past nine years of Washington state annual crop prices was used to estimate future variability patterns (WASS; Upadhyay and Young). Crop production expenditures were based on a survey of no-till farmers in the Palouse region (Camara, Young and Hinman).Tables 3 and 4 shows key parameters used in the model and summary statistics for historical yields and prices.

Results

A risk averse farmer is expected to prefer a lower breakeven no-till yield premium over conventional tillage. This implies a lower required elevation in the standard "learning curve" for the new no-till technology. The breakeven yield premiums under the short and long run decision criteria are described in Table 3 and 4. In each table, no-till breakeven yield premiums generate identical risks for no-till and conventional tillage. Breakeven premiums are presented for 10 transition strategies (five drill acquisition modes by two speeds of adoption) across four farm types. Yield premiums under short and long term decision criteria are discussed below.

Short run

Two consecutive years of negative cash flow is assumed as the measure of short run business failure. Breakeven no-till yield premiums in the short run varied with the type of farm (Table 3). Breakeven no-till yield premiums over the ten transition strategies for the high equity large farms (LFLPR) varied from 6 to 18 percent and were roughly similar for low equity large farms (LFHPR). Yield premiums ranged higher from 8 to 50% under both low and high proportion rented small farms (Table 3). Note that breakeven yield premiums in excess of 10 percent imply higher yields throughout the transition period with no-till than with conventional tillage. This may be more than most farmers can reasonably anticipate while learning a new no-till technology. Consequently, they may regard no-till as too risky when it requires such exceptional yield performance.

No-till yield premiums also varied across transition strategies under the short run criterion (Table 3). Comparisons can be facilitated by grouping those with eventual drill purchase (R-3, P-6, C-3) and those without drill purchase (R-6 and C-6). Transition strategies with drill purchase (irrespective of time of purchase) with a higher speed of no-till adoption required lower yield premiums. For example, yield premiums ranged from 6 to 8 percent for immediate adoption and from 16 to 18 percent for the gradual adoption for low proportion rented large farms (LFLPR). The lower breakeven yield premium under immediate adoption is driven by the economies of size for larger farms. The annual fixed cost per acre of a no-till drill can be reduced immediately when used over a larger area. Renting or custom hiring a drill and quicker adoption required a greater yield premium under these circumstances (Table 3). Custom hire, which also includes cost of skilled labor for drilling, required higher yield premiums than renting.

Long run

A farmer with greater ability and willingness to bear short run risk is expected to evaluate investment risk over a longer time horizon. For such farmers, it is assumed their definition of business failure is a cumulative negative cash balance at the end of the full six-year transition (Table 4).

As in the short run, yield premiums varied across farm types depending on transition strategies. As expected, yield premiums were slightly lower in the long run than in the short run for the same strategy-farm type combinations (Tables 3 and 4); however, for the riskiest situations the short run and long run premiums tended to converge . Yield premium ranged from 0 to 9 percent, 4 to18 percent, 6 to 50 percent, and 8 to 50 percent for LFLPR, LFHPR, SFLPR, SFHPR farm types, respectively. As expected, the yield premiums were lower for large than small farms. The low proportion rented farm required a smaller yield premium than the high proportion rented farm. The reason is that a farm with low proportion of rented land has lower cash outflows for rental payments. Consequently, a smaller increase in yield would be required to compensate for smaller cash shortfalls in the long run.

As in the short run, the expected yield premium varied with transition strategies for a type of farm. If the transition involved purchasing a drill, higher speed of adoption of no-till generally required a lower yield premium. Equal premiums were required for the low proportion rented large farm who rented or custom hired a drill half way through the transition. If the transition involved a rented or custom drill, quicker adoption always required higher yield premiums due to increased total variable costs with these strategies (Table 4).

Discussion of results

Some common patterns emerged from results in Table 3 and 4. No-till yield premium varied more with speed of adoption than the drill acquisition mode across both short and long run circumstances. For example, the difference between maximum and minimum yield premiums for a large farm with low proportion of rented land was 12 percent across speed of adoption and only 8 percent across drill acquisition modes in the short run (Table 3). These results suggest that economies of size advantages of immediate adoption dominate in risk reduction for large farms.

Irrespective of farm size, transition with a custom hired drill throughout usually required higher yield premiums than with renting. These results reflect the higher variable costs for custom hiring. As in the short run case, immediate adoption with a purchased drill decreased the required risk premium, especially for larger farms. If, for some reason gradual adoption was predetermined, transition with a rented drill minimized the yield premium for a large farm with a low proportion of rented land.

Summary and Conclusions

Adoption of a new technology such as no-till farming usually involves large multiyear cash outflows. Uncertainties in future prices and production generate risk of annual cash shortfalls. Failure to meet cash commitments can have serious financial consequences including foreclosure on capital purchases and even bankruptcy. This paper presents a new measure of the risk associated with technology adoption in terms of required breakeven yields to avoid short run and long run business failure.

Although probability of failure has been a popular method of communicating risk, required breakeven yield premiums may be easier for farmers to relate to. Prices are beyond the farmer's control, but the breakeven yield target a farmer must achieve to avoid business failure may be a more tangible measure of risk.

Breakeven no-till yield premiums were obtained using Monte Carlo simulation for ten no-till transition strategies across four types of Washington state, USA farms. Farms differed in size and the proportion of rented land. Major findings of the study showed yield premiums were lower for larger farms than smaller farms due to economies of size in machinery use. In general, custom hiring of no-till drills required a higher yield premium than with renting, mainly due to higher variable costs with custom hiring. Breakeven yield premiums for no-till varied more with speed of adoption than with drill acquisition mode. Immediate adoption with a purchased drill minimized the yield premium, especially on larger farms. Gradual adopters minimized yield premiums with rented or custom hired drill. Unlike large farms, a small farm more often minimized yield premiums with gradual adoption. As expected, breakeven yield premiums for no-till were lower for a long run measure of business failure than for a short run measure.

Adopters of new technology will often have to navigate a learning curve during which crop yields or other production will take time to reach a sustained high level. This study provides a practical approach to measuring the risk of technology adoption by reporting the expected breakeven production level the operator must achieve to avoid business failure. The stochastic breakeven yield model introduced here could be applied to other technology adoption decisions where entrepreneurs experience a learning curve in mastering the technology.

References

Anderson, K.B., and H.P. Mapp. “ Risk Management Programs in Extension.” *J. Agr. and Resource Econ.* 21(1996):31-38.

Boerboom, C.M., F.L. Young, T. Kwon, and T. Feldick. *IPM Research Project for Inland Pacific Northwest Wheat Production*. Agric. Res. Ctr. Bull. XB1029, Washington State University, 1993.

Buschena, D.E. and D. Zilberman. “ What Do We Know About Decision Making Under Risk and Where Do We Go From Here?” *J. Agr. and Resource Econ.*19 no.2(1994):425-445.

Camara, O.M., D.L. Young, and H.R. Hinman. *Economic Case Studies of Eastern Washington and North Idaho No-till Farmers Growing Wheat, Barley, Lentils, and Peas in the 19-22 Inch Precipitation Zone*. Farm Business Management Report EB 1886, Washington State University, 1999.

Castle, E.N. “ On The Communication Gap in Agricultural Economics.” *Amer. J. Agr. Econ*. 75(1993):84-91.

Hardaker, J.B., R.B.M. Huirne, and J.R Anderson. *Coping With Risk in Agriculture*. NY: CAB International, 1997.

Hall, M. J. Economics of Weed Management and Farming Systems in the Palouse Region. M.A. thesis, Washington State Univ., Pullman, 1995.

Iowa State University. FAPRI Price Projections (various years).

Janosky, J.S., D.L. Young, and W.F. Schillinger. “Economics of Conservation Tillage in a Wheat-Fallow Rotation.” *Agron. J.* 94(2002):527-531.

Juergens L., D. Young, D. Roe, and H. Wang. “Preliminary Farmer Survey Results on the Economics of the Transition to No-till.” In J. Burns and R. Veseth (Editors) *Field Day Proceedings: Highlights of Research Progress*. Tech. Report 01-04, pages 112-114. Dept. Crop and Soil Sciences, Wash. State University, Pullman, 2001.

Just, R.E. “ Risk Research in Agricultural Economics: Opportunities and Challenges for the Next Twenty-Five Years.” *Agr. Systems* 75(2003):123-159.

Kataoka, S. “A Stochastic Programming Model.” *Econometrica* 31(1963):181-196.

Kingwell, R.S., D.J. Pannell, and S.D. Robinson. “ Tactical Responses to Seasonal Conditions in Whole Farm Planning in Western Australia.” *Agric. Econ*. 8(1993):211-216.

Lien, G. “ Assisting Whole-Farm Decision-Making through Stochastic Budgeting.” *Agr. Systems* 76(2003):399-413.

Mitchell, D.O. and J.R. Black. “Incorporating Aggregate Forecasts into Farm Firm Decision Models,” pages 73-87. In K.H. Baum and L. P. Schertz (Editors) *Modeling Farm Decision for Policy Analysis*. Boulder, Colorado:Westview Press, 1983.

Ortmann, G.F., G.F. Patrick, W.G. Musser, and D.H. Doster. *Information Sources, Computer Use and Risk Management Evidence From Leading Commercial Cornbelt Farmers*. Bulletin 638. Agricultural Experiment Station, Purdue University, West Lafayette, IN, 1992.

Pannell, D.J., Malcolm, L.R. and Kingwell, R.S. Are We Risking Too Much? Perspectives on Risk in Farm Modelling. *Agricultural Economics* 23(2000): 69-78.

Papendick, R.I. “Farming Systems and Conservation Needs in the Northwest Wheat Region.” *Am. J. Alternative Agric.* 11(1996):52-57.

Papendick, R.I. (ed.) *Farming with The Wind: Best Management Practices for Controlling Wind Erosion and Air Quality on Columbia Plateau Croplands*. Washington State University, College of Agric. and Home Econ. Misc. Pub. No. MISC0208, Pullman, WA, 1998.

Richardson, J.W. *Simulation for applied risk management with an introduction to the software package Simetar©: Simulation for Excel to analyze risk*. Department of Agricultural Economics, Texas A&M University, College Station, Texas, 2002.

Richardson, J.W., S.L. Klose, and A.W.Gray. “An Applied Procedure for Estimating and Simulating Multivariate Empirical Probability Distributions in Farm Level Risk Assessment and Policy Analysis.” *J. Agr. and Appl. Econ*. 32(2000):299-315.

Roy, A.D. “Safety First and the Holding of Assets.” *Econometrica* 20(1952):431-439.

Schilllinger, W.F. “Minimum and Delayed Conservation Tillage for Wheat Fallow Farming.” *Soil Sc. Soc. Am. J.* 65(2001)1203:1209.

Selley, R.A. and P.N. Wilson. “ Risk Research and Public Outreach: A tale of Two Cultures? *J. agr. and resour. Econ*.22(1997):222-232.

Telser, L. “Safety First and Hedging.” *Review of Econ. Studies* 23(1955):1-6.

Upadhyay, B.M. and D.L. Young. “An Operational Approach for Evaluating Investment Risk: An Application to the No-till Transition. *Journal of Financial Risk Management*, ICFAI University Press, 3(2)(2006): 25-37.

WASS (Washington Agricultural Statistics Services) (1986-1994), *Washington Agricultural Statistics*, Olympia.

Young, D.L., T. Kwon, and F.L. Young. “Profit and Risk for Integrated Conservation Farming Systems in the Palouse.” *J. Soil and Water Cons*. 49 no.6 (1994):601-606.

Table 1. Descriptions of key parameters of the model

No-Till drill acquisitions

Rent: $12.00 per acre

Custom Hire: $20.00 per acre

Purchase price: $53,750.00; down payment 30% , interest 8% and 5 year repayment period

Production costs

Labor: $14.00 per hour

Overhead: 5% of total variable cost

Inflation: 3% per annum

Crop share arrangements

Wheat and barley: 1/3 of crop revenue- 1/3 crop insurance- 1/3 fertilizer expense

Spring pea: 1/4 crop revenue-1/4 crop insurance

Tax, family living expenditures and interest on cash flow

Land tax: $5.5 per acre

Income tax: according to IRS provision on 2001

Family living withdrawal: $32,073 to $29,018 for large farm and $19,994 to $17,118 for small farm depending on proportion of rented land which increase in subsequent year at the rate of 3% per annum

Interest: 6% on cash reserve and 8% on borrowing

Government payment

Deficiency payment, loan payment and counter cyclical payment according to the provision of 2002 farm bill which is shared between land lord and renter at the proportion corresponding to crop share.

Table 2. Historical average and standard deviation of yields and prices

	Unit	Mean	StDev
Conventional Tilled			
Winter Wheat	Bu/ac	86.08	24.43
Spring Barley	Bu/ac	83.57	29.34
Spring Pea	Cwt/ac	16.89	6.61
No-tilled			
Winter Wheat	Bu/ac	*	22.14
Spring Barley	Bu/ac	*	29.32
Spring Pea	Cwt/ac	*	6.21
Prices			
Winter Wheat	$/ Bu	3.39	0.59
Spring Barley	$/ Bu	2.15	0.3
Spring Pea	$/ Cwt	9.02	1.28

* No-till mean yield in the first year is computed as, $Y_1^N = 0.9(Y_1^C)$
No-till yield in the following year are computed as, $Y_t^N = Y_{t-1}^N(1+\gamma)$ where γ is the slope of learning curve.

Table 3. No-till yield premiums (%) over conventional tillage (100%) corresponding to transition strategies for four types of farm using short run two consecutive years of negative cash balances criterion

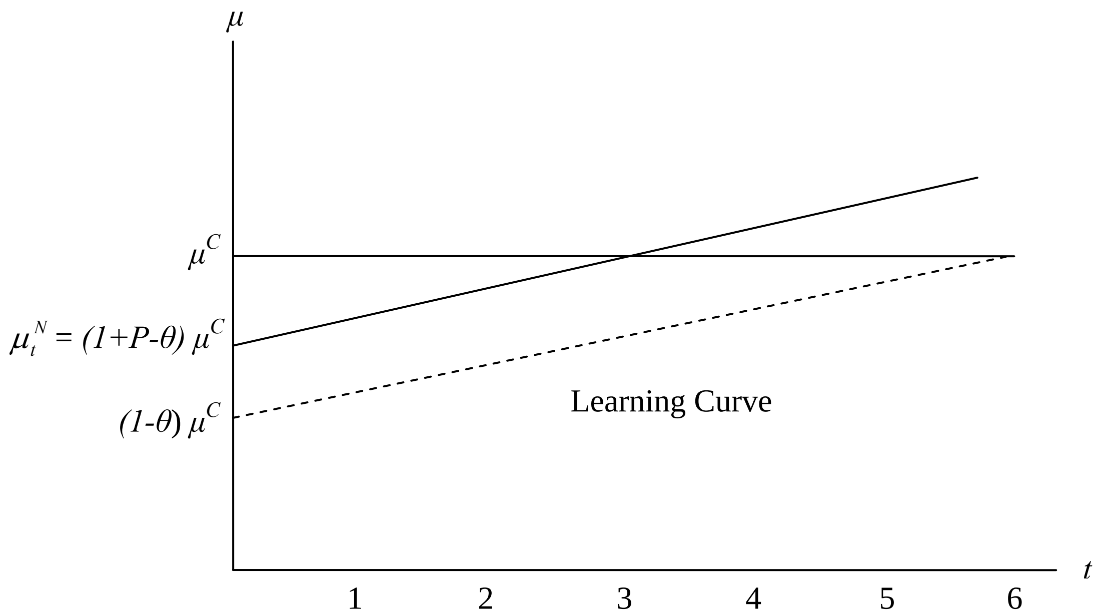
	LFLPR		LFHPR	
Strategies	IA	GA	IA	GA
R-6	112	110	109	108
R-3	107	116	106	112
P-6	106	118	104	116
C-3	108	116	109	112
C-6	113	112	111	110
Strategies	SFLPR		SFHPR	
R-6	109	108	108	108
R-3	112	140	111	140
P-6	111	150	110	150
C-3	113	140	113	140
C-6	111	112	111	110

Note: IA and GA equal immediate adoption and gradual adoption. LFLPR, LFHPR, SFLPR, and SFHPR represent the four farm types. LF and SF refer to large (3,000 acres) and small (800 acres) farms. LPR and HPR refer to low (0.2) and high (0.8) proportion of rented land. Drill acquisition decisions in the first column are renting (R), custom hiring (C), and purchasing (P). The number 6 and 3 shows the number of years the option was used in the six-year transition. The drill was purchased in the remaining years.

Table 4. No-till yield premiums (%) over conventional tillage (100%) corresponding to transition strategies for four types of farms using long run ending period negative cash balance criterion

	LFLPR		LFHPR	
Strategies	IA	GA	IA	GA
R-6	106	100	109	108
R-3	104	104	107	112
P-6	102	108	104	118
C-3	106	106	109	112
C-6	109	102	112	110
Strategies	SFLPR		SFHPR	
R-6	108	106	109	108
R-3	111	130	112	140
P-6	110	150	111	150
C-3	112	130	114	140
C-6	111	108	112	112

Note: LFLPR, LFHPR, SFLPR, and SFHPR are the four farm types. LF and SF refer to large (3,000 acres) and small (800 acres) farm. LPR and HPR refer to low (0.2) and high (0.8) proportion of rented land. Drill acquisition decisions are renting (R), custom hiring (C), and purchasing the no-till drill (P). The number 6 and 3 shows the number of years the option was used in the six-year transition. The drill was purchased in the remaining years.



Note: μ the mean yield over t years, subscript t denotes tth year, superscript C and N refer to conventional and no-till. θ is the yield penalty due to no-till learning curve. P is the yield premium required by no-till strategies to break even with the safety-first risk in conventional tillage.

Figure 1. Diagrammatic representation of learning curve and yield premium relative to conventional tillage yield